APPENDIX G

BIOFILTRATION APPLICATION GUIDE (REVISED)

- General Criteria and Guidelines
- Design and Installation Criteria and Guidelines
- Operation and Maintenance Criteria and Guidelines
- Biofilter Design Procedure and Example
- Example (Biofiltration Swale)

APPENDIX G

BIOFILTRATION APPLICATION GUIDE (REVISED)

This guide provides biofilter design criteria and procedures in full detail, along with examples. Refer to Section 7 for background on specific provisions. This guide updates and assembles in one place the application guide presented in the Phase I report (Horner, 1988). It continues the practice established in the earlier report of covering both biofiltration swales and filter strips, because of the similarity of these two techniques, although the latter was not specifically investigated in Phase II of the research.

GENERAL CRITERIA AND GUIDELINES

Planning Considerations

1. Local governments should maintain the necessary flexibility in ordinances and regulations to permit site-by-site assessment of biofiltration alternatives, and to allow for discretionary design, installation, operating, and maintenance requirements, as long as they do not conflict with the general intent of requirements stated below.

2. Biofiltration should be regarded as one possible element of an integrated stormwater management plan for any given site or class of sites. Selection and implementation of alternatives should be based on stated water quality objectives. The plan should emphasize preventive source control measures to the maximum extent possible. It should then incorporate treatment techniques, such as biofiltration, as necessary to achieve the objectives. Meeting the objectives may require the use of two or more techniques that have complementary features in a treatment train; the analysis of options should consider such applications.

3. With diverse opportunities existing to apply the variety of biofilter configurations, a creative approach is recommended to obtain the best match of system and conditions.

4. Since biofiltration is an onsite rather than regional technique, localized commitments should be made to maximize its application and effectiveness.

5. Local governments should establish basic educational programs on biofilters (probably in conjunction with other stormwater management issues) for builders, engineers, landscape designers, public officials, and citizens. These programs should cover the benefits of biofilters, what is needed for their effectiveness, and how they can serve as a landscape amenity.

6. Since flexibility exists in many design features, biofiltration success depends more on proper construction and maintenance than any other factors; effective inspection and enforcement programs should be emphasized to ensure that approved plans are implemented.

7. Local governments should obtain access easements to biofilters on private land as necessary to accomplish anticipated inspection, monitoring, and maintenance. If water quality monitoring will be performed, the parties should agree on the provision of the needed facilities prior to construction of the biofilter.

8. Local governments should develop policies on long-term maintenance for privately owned biofilters. Possible approaches include holding a maintenance bond for a period of time or performing the maintenance and billing the owner. If maintenance will be the owner's responsibility, the local government should require the filing of a maintenance schedule. If public crews will perform maintenance, they should have the opportunity to review designs before construction.

General Technical Considerations

1. Natural drainage courses should be regarded as significant local resources that are generally to be kept in use for stormwater conveyance. Use of natural topographic lows for biofiltration is encouraged.

2. Roadside ditches should be regarded as significant potential biofiltration sites; road design standards and ditch maintenance programs should be developed to maximize their usefulness in biofiltration.

3. Local governments should resist proposals to enclose open channels in pipes. In addition to offering the opportunity for biofiltration, open channels generally have more capacity than pipes and are easier to inspect and maintain.

4. The use of biofilters in connection with other treatment devices should be carefully analyzed with reference to water quality objectives and site conditions. If there is a significant potential for discharge of sediment or oil and grease into the biofilter, the necessary controls should be placed upstream to minimize the entrance of these materials. These controls might include a catch basin when the sedimentation potential is relatively small, or a larger presettling device with greater potential, and an oil/water separator either as a spill control catch basin or a separate device. If a retention/detention pond is required for runoff quantity control at the site, the biofilter should normally follow it in order to receive regulated flow introduction and presettling benefits.

5. Where sufficient land does not exist for both a runoff quantity control pond and a biofilter, nesting a circular biofilter around the circumference of a pond should be considered to allow for both treatment of low flows and the required quantity control.

6. Opportunities to fit biofiltration retroactively to areas already developed should be exploited whenever possible, especially when they redevelop.

7. Biofilters should generally not receive construction-stage runoff; if they do, presettling of sediments should be provided. Such biofilters should be evaluated for the need to remove sediments and restore vegetation following construction.

DESIGN AND INSTALLATION CRITERIA AND GUIDELINES

Provisions Applying to Swales and Filter Strips

1. For biofiltration, it is important to maximize water contact with vegetation and the soil surface. Graveled and coarse sandy soils cannot be used for biofiltration unless the bottom of the swale is lined to prevent infiltration. (Note: Sites that have relatively coarse soils may be more appropriate for stormwater infiltration areas.) Also, avoid very heavy clay soils that would not support good vegetation growth. In general, use of 6 inches (15 cm) of the following topsoil mix is recommended: 50 to 80 percent sandy loam, 10 to 20 percent clay, and 10 to 20 percent composted organic matter (excluding animal waste). Exclude materials toxic to vegetation, stones, and other debris. Where suitable, use on-site material. Attempt to avoid soil compaction during construction; if compaction occurs, till before planting.

2. If the percolate from a biofilter could contaminate groundwater, seal the bed with clay or a geotextile.

3. Vegetate biofilters uniformly with fine, close-growing, water resistant grasses where conditions are conducive to their establishment and survival. On sites where the biofilter will intercept groundwater or where there is little or no slope to allow for good drainage, emergent herbaceous wetland vegetation is an acceptable planting alternative.

4. It is preferable that vegetation species selected for biofilters be native to the region of application. Considerable hybridization of grasses may make this preference unrealizable in full, but selected species should be demonstrated to establish and survive well in the regional conditions with minimal needs for fertilization, pest control, and irrigation. Native wetland plants can be obtained from specialized nurseries. Weedy species that tend to be invasive in disturbed and managed environments should always be avoided; these species include *Phalaris arundinaceae* (reed canarygrass), *Lythrum salicaria* (purple loosestrife), *Phragmites* spp. (reeds), and *Iris pseudocorus* (yellow iris). Cattails (*Typha* spp.), while advantageous for several reasons, are discouraged because of their tendencies toward opportunistic spreading and clumping. Grass mixes that have been used with good results in the Puget Sound region include the following:

City of Mountlake Terrace	Shapiro and Associates, (Seattle)
66.67 percent Tall fescue	40.0 percent Redtop bentgrass
15.80 percent Seaside bentgrass	30.0 percent Red fescue
9.21 percent Meadow foxtail	20.0 percent Tall fescue
5.92 percent Alsike clover	5.0 percent Perennial rye
0.88 percent Marshfield big trefoil	5.0 percent Russian wildrye
1.47 percent Inert matter	
0.05 percent Weed seed	

Pacific Northwest wetland species that have favorable characteristics for biofiltration include the following:

- *Juncus* spp. (rushes), especially *J. tenuis* and *J. ensifolius* (dagger rush); excluding *J. effusus* (soft rush)
- *Scirpus* spp. (bulrushes), especially *S. microcarpus* (small-fruited bulrush), *S. validus*, *S. acutus*

- *Carex* spp.
- *Eleocharis* spp. (spike rushes)
- *Sparganium euycarpum* (burreed)
- *Lemna* spp. (duckweeds)
- *Oenanthe sarmentosa* (water parsley)

5. Consider the possibility and desirability of wildlife habitat developing in concert with pollution control. If warranted, consider the needs of such development in vegetation selection.

6. Use grass seed and mulch application rates specified by the supplier. Do not use animal manure mulch within the biofilter. Avoid fertilizer application whenever possible, and never use fertilizers in amounts exceeding plant uptake rates and the requirements imposed by soil conditions. Attempt to establish grasses when natural moisture is adequate, but irrigate if necessary to ensure good establishment. If wetland plants are used, protect them from predation by netting during establishment.

7. Avoid heavy and prolonged shading of the biofilter by adjusting its placement relative to buildings and trees.

8. Vegetate the ground upslope from the grassed treatment area of the biofilter to prevent erosion. Additional grass or nonaggressive ground covers are appropriate. Barrier shrubs, such as barberry, surrounding the biofilter should be considered when there is a high potential for damaging its functioning through intrusion by people or domestic animals. Attempt to minimize shading of vegetation in the biofilter treatment area when planting trees. The amount of shading that occurs depends on the tree species selected, their proximity to the biofilter, and their spacing. If some shading cannot be avoided, select species and specify placement to avoid continuous shading along the biofilter's length. A spacing of at least 20 feet (6 meters) is appropriate for many trees that are commonly used in landscaping when they are planted close to a biofilter.

9. Landscape beds near biofilters should preferably be at a slightly lower elevation, or at least no higher, than the ground surface. The use of bark, mulch, fertilizers, and pesticides is discouraged in these areas; but if they are used, recessing beds or edging level beds are especially recommended.

10. The longitudinal slope (parallel to the flow) of biofilters should normally be between 2 and 4 percent. If the slope is 1 to 2 percent, install an underdrain with perforated pipe or, if moisture is adequate, establish wetland species. If an underdrain is used, use topsoil with a relatively large proportion of sand. Place the perforated pipe (6 inches minimum diameter) in a trench filled with 5/8-inch minus round rocks and lined with Mirafi 140 NS or equivalent filter fabric. The pipe should be at least 12 inches below the biofilter bed.

11. If the slope is between 4 and 6 percent, add vertical drops (6 to 12 inches, 15 to 30 cm) through the use of level check dams at 50- to 100-foot (15 to 30 meter) intervals. Install energy dissipating and flow spreading rip-rap across check dams and for a short distance downstream at the toe of drops.

12. If the slope is greater than 6 percent, traverse the grade to reduce the slope of any segment to below 4 percent, preferably, or to below 6 percent with check dams.

13. Grade biofilters carefully to attain uniform longitudinal and lateral slopes and to eliminate high and low spots. If the grading equipment blade is wider than the swale bottom width, obtain a smaller blade or employ hand finishing in order to ensure uniformity.

14. If possible, divert runoff (other than necessary irrigation) during the period of vegetation establishment. This requirement can normally be met in the Pacific Northwest by planting during July or August. However, irrigation may be needed at that time. If biofilters must be installed in a period of high runoff, they should be established by sodding. Since sod is not available in recommended grasses, it should be oversown with a recommended mix at the beginning of the growing season.

15. If flow is to be introduced via curb cuts, place pavement slightly above the biofilter elevation. Curb cuts should be at least 12 inches wide to prevent clogging.

16. Install a flow-spreading device to uniformly distribute flow at the biofiltration swale inlet or across the width of a filter strip. Appropriate devices include shallow weirs, stilling basins, and perforated pipes. Provide a sediment clean-out area.

17. Provide for energy dissipation at the inlet. Appropriate means are stilling basins and rip-rap pads. If rip-rap is used, 6- to 9-inch

(15- to 23-cm) rocks should be fit tightly together across the bed and for a distance of 5 to 10 ft (1.5 to 3 meters) downstream. If vandalism is likely, embed the rocks in concrete.

18. Consider the need for a high-flow bypass. A bypass will not be needed if the biofilter is preceded by a runoff quantity control device designed according to standards equivalent to those of Ecology's stormwater management manual for the Puget Sound Basin. A bypass should especially be considered if the biofilter discharges directly to a sensitive receiving water without quantity control, in order to maintain the vegetation in a condition to treat subsequent smaller storms. If a bypass is used, it should consist of an inlet flow regulating device and a pipe or reinforced channel.

Provisions for Swales

1. Design swales for biofiltration capacity and stability according to the method detailed in the Biofilter Design Procedure below. Base the capacity design for biofiltration on the 6-month frequency, 24-hour duration peak flow rate. Unless runoff from larger events will bypass the swale, base the capacity design for flood passage on the 100-year frequency, 24-hour duration peak flow rate, plus 1-foot (30-cm) freeboard.
2. Base the biofiltration capacity design on the following criteria (to be met or exceeded during the biofiltration capacity design event):
   - Hydraulic residence time normally no less than 9 minutes, and in no case less than 5 minutes (If flow enters the swale at intermediate points between the inlet and outlet, the average residence time should meet this criterion.)
   - Average velocity no greater than 0.9 feet per second (27 cm/s)
   - Manning's n of 0.2 for routine swales that will be mowed with some regularity, 0.24 for infrequently mowed swales, or a selected higher value if it is known that vegetation will be very dense
   - Maximum width of 8 feet (2.4 meters), unless special measures will be taken to distribute flow, smooth the bed, and mow; minimum width of about 2 ft (0.6 meter)
   - Average depth of flow no greater than one third of the grass or emergent wetland vegetation height for infrequently mowed

swales, or no greater than one half of the vegetation height for regularly mowed swales, up to a maximum of 3 inches (7.5 cm) for grass and 2 inches (5 cm) below the normal height of the shortest species in a wetland plant biofilter

- Minimum length of 100 ft (30 meters)

3. Base the design on a trapezoidal cross section for ease of construction. A parabolic shape will evolve over time. Make side slopes not steeper than 3 horizontal:1 vertical wherever possible. If a slope steeper than 2:1 must be used, it will require stabilization.

4. Use a wide-radius curved path to gain length where land is not adequate for a linear swale (avoid sharp bends to reduce erosion or provide for erosion protection).

Provisions for Filter Strips

1. Design filter strips for biofiltration capacity according to the same method detailed in the Biofilter Design Procedure below and the 6-month frequency, 24-hour duration peak run-off rate.

2. Base the design on the following criteria (to be met or exceeded during the design event):

   - Hydraulic residence time normally no less than 9 minutes, and in no case less than 5 minutes
   - Average velocity no greater than 0.9 feet per second (27 cm/s)
   - Manning's n of 0.2 for routine strips that will be mowed with some regularity, 0.24 for infrequently mowed strips, or a selected higher value if it is known that grass will be very dense
   - Width no greater than uniform flow distribution can be assured
   - Average depth of flow no more than 0.5 inch (1.25 cm)
   - Hydraulic radius taken to be equal to the design flow depth.

OPERATION AND MAINTENANCE CRITERIA AND GUIDELINES

1. Keep the inlet flow spreader even and free of leaves, rocks, and other debris.

2. For groomed biofilters planted in grasses, mow regularly during the summer to promote growth and pollutant uptake and remove debris. Be sure not to cut within 2 inches of the design flow depth (maintenance personnel must be made aware of this requirement). Remove cuttings promptly, and dispose in a way so that no pollutants can enter receiving waters. Unless visibly tainted, dispose of clippings in the same manner as yard waste. Otherwise, bag and take to a sanitary landfill.

3. If the objective is prevention of nutrient transport, mow grasses or cut emergent wetland-type plants to a low height at the end of the growing season. For other pollution control objectives, let the plants stand at a height exceeding the design water depth by at least 2 inches (5 cm) at the end of the growing season.

4. Remove sediments by hand with a flat-bottomed shovel during the summer months whenever sedimentation covers vegetation or begins to reduce the biofilter's capacity. Have the grass cut short so that the bed can be made as level as possible.

5. Reseed damaged or maintained areas immediately with a mix such as that recommended above for initial establishment, or grass plugs from an adjacent upslope area. If possible, redirect flow until the new grass is firmly established. Otherwise, cover the seeded areas with a high quality erosion control fabric.

6. Inspect biofilters periodically, and especially after heavy runoff (preferably, monthly and after each storm that delivers 0.5 inch or more of rainfall). Remove sediments and repair vegetation as necessary.

7. Clean curb cuts when soil and vegetation buildup interferes with flow introduction.

8. Perform special public education for residents near biofilters, concerning their purpose and the importance of keeping them free of lawn debris and pet wastes.

9. See that litter and other debris are removed in order to keep biofilters attractive in appearance and reduce the tendency to channelization when trash accumulates.

10. Base roadside ditch cleaning on an analysis of hydraulic necessity. Use a technique such as the Ditch Master to remove only the amount of sediment necessary to restore needed hydraulic capacity, leaving vegetative plant parts in place to the maximum extent possible.

BIOFILTER DESIGN PROCEDURE AND EXAMPLE

Procedure

The procedures for swale and filter strip design are basically the same. The steps are given in full for swales, and notes are included to allow the procedure to be applied to filter strips as well. Unless specifically indicated, steps apply to both swales and filter strips.

Preliminary Steps (P)

P-1. Estimate runoff flow rate (Q) for the 6-month frequency, 24-hour duration storm.

Use a method acceptable to the local government and the situation, such as the method outlined in Chapter III-1 of Ecology's Stormwater Management Manual for the Puget Sound Basin, or an appropriate computer model.

Attempting to treat excessive flows in a biofilter will cause violations of the criteria stated above. For example, a Q approaching one cfs for common slopes would require a swale that violates one or more of the criteria on width, flow depth, or velocity. Moreover, achieving the hydraulic residence time specified would often require a very long swale for high values of Q. It is therefore recommended the ways be investigated to lower the design flow when an initial estimate is in the vicinity of 1 cfs or higher, if a swale is the anticipated form of biofilter (filter strips can accept higher flows if adequate land is available). Possibilities include dividing the flow among several swales, installing detention to control release rate upstream, and reducing the developed surface area to reduce runoff coefficient and gain space for biofiltration.

P-2. Establish the slope of the proposed biofilter. For guidance refer to Provisions Applying to Swales and Filter Strips (numbers 10-12) above.

P-3. Select a vegetation cover suitable for the site. For guidance refer to Provisions Applying to Swales and Filter Strips (numbers 3-5) above.

Design for Biofiltration Capacity (D)

There are a number of ways of applying the design procedure introduced by Chow (1959). These variations depend on the order in which steps are performed, what variables are established at the beginning of the process and which ones are calculated, and what values are assigned to the variables selected initially. The procedure recommended here is an adaptation appropriate for biofiltration applications of the type being installed in the Puget Sound region. This procedure reverses Chow's order, designing first for capacity and then for stability. The capacity analysis emphasizes the promotion of biofiltration, rather than transporting flow with the greatest possible hydraulic efficiency. Therefore, it is based on criteria that promote sedimentation, filtration, and other pollutant removal mechanisms. Since these criteria include a lower maximum velocity than permitted for stability, the biofilter dimensions usually do not have to be modified after a stability check.

D-1. Establish the height of vegetation during the winter and the design depth of flow.

Maximizing height advances biofiltration and allows greater flow depth, which reduces the width necessary to obtain adequate capacity. However, if nutrient capture is the principal objective, vegetation should be mowed at the end of the growing season to minimize nutrient release. The design depth of flow should be at least 2 inches less than the winter vegetation height, and a maximum of 3 inches in swales and 0.5 inch in filter strips.

D-2. Select a value of Manning's n as follows:

Routine swales that will be mowed with some regularity (also use for routine emergent herbaceous wetland plant applications)—0.20.

Infrequently mowed swales—0.24.

When it is known that vegetation will be very dense—selected.

D-3. Select the swale shape. Skip this step in filter strip design.

Normally, swales are designed and constructed in a trapezoidal shape. The following steps also give formulas for parabolic, rectangular, and V-shapes. A parabolic shape best resists erosion, but is hard to construct. A rectangular shape should only be used in a very confined space. For a rectangular swale specify reinforcement for the side walls in conformance with the standards of the local government. Do not specify a V-shape; the formulas are given only for analysis of swales already in place.

D-4. Use Manning's Equation and first approximations relating hydraulic radius and dimensions for the selected shape to obtain a working value of a biofilter width dimension:

$$Q \cong \frac{1.49}{n} AR^{0.67} s^{0.5} \qquad \text{Eq. G-1}$$

Where: Q = design runoff flow rate (ft^3/s, cfs)

n = Manning's n (dimensionless)

A = Cross-sectional area (ft^2)

R = Hydraulic radius = A/wetted perimeter (ft)

s = longitudinal slope as a ratio of vertical rise/horizontal run (dimensionless)

Refer to Figure G-1 to obtain equations for A and R for the selected shape. In addition to these equations, for a rectangular shape:

$$A = Ty \qquad \text{Eq. G-2}$$

$$R = \frac{Ty}{T+2y} \qquad \text{Eq. G-3}$$

Where: T = width

y = depth of flow

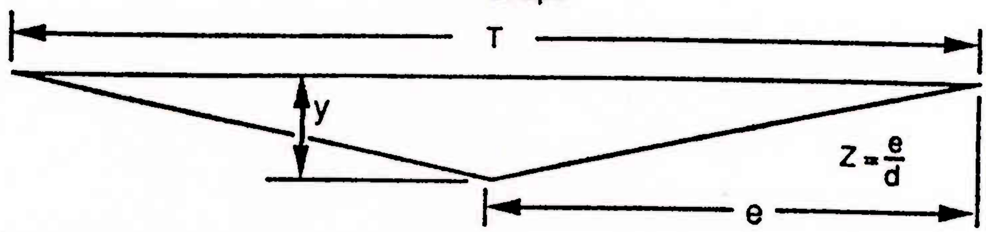
If these expressions are substituted in Eq. G-1 and solved for T (for previously selected y), the results are complex equations that are difficult to solve manually. However, approximate solutions can be found by recognizing that $T >> y$ and $z^2 >> 1$, and that certain terms are nearly negligible. The approximations for the various shapes are:

Parabolic:	$R \cong 0.67\,y$	Eq. G-4
Trapezoidal:	$R \cong y$	Eq. G-5
V:	$R \cong 0.5\,y$	Eq. G-6
Rectangular:	$R \cong y$	Eq. G-7

(Also use for filter strips.)

CHANNEL GEOMETRY

V - Shape

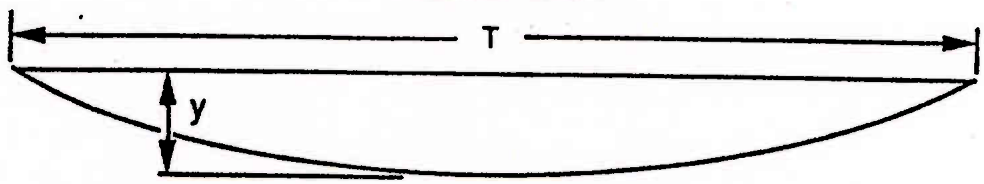


Cross-Sectional Area (A) = Zy^2

Top Width (T) = $2yZ$

Hydraulic Radius (R) = $\dfrac{Zy}{2\sqrt{Z^2 + 1}}$

Parabolic Shape

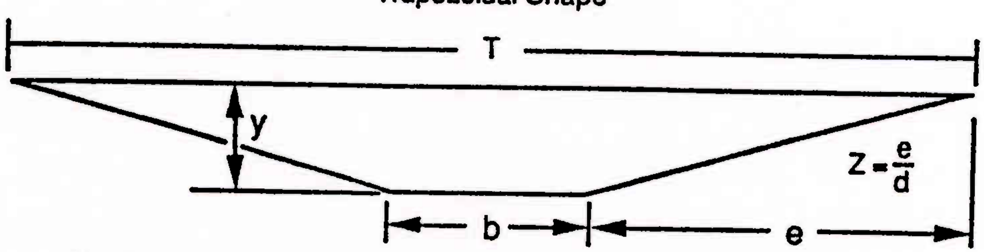


Cross-Sectional Area (A) = $\frac{2}{3}Ty$

Top Width (T) = $\dfrac{1.5A}{y}$

Hydraulic Radius (R) = $\dfrac{T^2 y}{1.5T^2 + 4y^2}$

Trapezoidal Shape



Cross-Sectional Area (A) = $by + Zy^2$

Top Width (T) = $b + 2yz$

Hydraulic Radius (R) = $\dfrac{by + Zy^2}{b + 2y\sqrt{Z^2 + 1}}$

Figure G-1. Geometric Formulas for Common Swale Shapes (Livingston et al., 1984)

Making these substitutions and those for A from Figure G-1, and then solving for T gives:

Parabolic: $$T \cong \frac{Qn}{0.76\ y^{1.67}\ s^{0.5}}$$ Eq. G-8

Trapezoidal: $$b \cong \frac{Qn}{1.49\ y^{1.67}\ s^{0.5}} - Zy$$ Eq. G-9

V: $$T \cong \frac{Qn}{0.47\ y^{1.67}\ s^{0.5}}$$ Eq. G-10

Rectangular: $$T \cong \frac{Qn}{1.49\ y^{1.67}\ s^{0.5}}$$ Eq. G-11

(Also use for filter strips.)

For trapezoidal and V-shapes, select a side slope Z of at least 3.

Solve the appropriate equation for T and/or b. For a V-shape, check if $Z = T/2y$ is at least 3.

If b for a swale is greater than 8 ft, either investigate how Q can be reduced or arbitrarily set b = 8 ft and continue with the analysis. (b for a filter strip can be as great as uniform flow distribution can be assured.)

If b for a swale is less than 2 ft, set b = 2 ft and proceed.

D-5. Compute A using the appropriate equation from Figure G-1 or Eq. G-2.

D-6. Compute the flow velocity at design flow rate:

$$V = \frac{Q}{A}$$ Eq. G-12

This velocity should be less than 0.9 feet per second, a velocity that was found to cause grasses to be knocked from a vertical position, thus reducing filtration. If V > 0.9 feet per second, repeat steps P-1 through D-6 until this condition is met. A velocity lower than this maximum value is recommended because it will permit achieving the 9-minute hydraulic residence time criterion in a shorter biofilter (at V = 0.9 feet per second, a 486-ft long biofilter is needed for a 9-minute residence time and a 270-ft long biofilter for a 5-minute residence time, the absolute minimum). If the value of V suggests that a longer biofilter will be needed than space permits, investigate how Q can be reduced, or increase y and/or T (up to the allowable maximum values) and repeat the analysis.

D-7. Compute the swale length (L, ft):

$L = (V)(t)(60 \text{ seconds/minute})$ Eq. G-13

Where: t = hydraulic residence time (min)

Use t = 9 min for this calculation. If a biofilter length greater than the space permits results, follow the advice in step D-6. If all of these possibilities have been thoroughly checked and the space is still insufficient, t can be reduced, but to no less than 5 min.

If L < 100 ft results from this analysis, increase it to 100 ft, the minimum allowed. In this case it may be possible to save some space in width and still meet all criteria. This possibility can be checked by computing V in the 100 ft biofilter for t = 9 min, recalculating A from Eq. G-12 (if V < 0.9 feet per second), and recalculating T from one of the equations referenced in step D-5.

Check for Stability (Minimizing Erosion) (S)

The stability check must be performed for the combination of highest expected flow and least vegetation coverage and height.

Maintain the same units as in the biofiltration capacity analysis.

S-1. Unless runoff from events larger than the 6-month, 24-hour storm will bypass the biofilter, perform the stability check for the 100-year, 24-hour storm. Estimate Q for that event as recommended in Preliminary step 1.

S-2. Estimate the vegetation coverage ("good" or "fair") and height on the first occasion that the biofilter will receive flow, or whenever the coverage and height will be least. Attempt to avoid flow introduction during the vegetation establishment period by timing of planting or bypassing.

S-3. Estimate the degree of retardance from Table G-1. When uncertain, be conservative by selecting a relatively low degree.

Table G-1. Guide for Selecting Degree of Retardance (a)	
Average Grass Height (inches)	Degree of Retardance
Good	
>30	A. Very high
11-24	B. High
6-10	C. Moderate
2-6	D. Low
<2	E. Very low
Fair	
>30	B. High
11-24	C. Moderate
6-10	D. Low
2-6	D. Low
<2	E. Very low

(a) After Chow (1959). In addition, Chow recommended selection of retardance C for a grass-legume mixture 6 to 8 inches in height and D for the mixture 4 to 5 inches high. No retardance recommendations have appeared for emergent wetland species. Therefore, judgment must be used. Since these species generally grow less densely than grasses, using a "fair" coverage would be a reasonable approach.

S-4. Establish the maximum permissible velocity for erosion prevention (V_{max}) from Table G-2.

Table G-2. Guide for Selecting Maximum Permissible Swale Velocities for Stability*

Cover	Slope (percent)	Maximum Velocity (feet per second [m/s])	
		Erosion-Resistant Soils	Easily Eroded Soils
Kentucky bluegrass Tall fescue	0-5	6 [1.8]	5 [1.5]
Kentucky bluegrass Ryegrasses Western wheat-grass	5-10	5 [1.5]	4 [1.2]
Grass-legume Mixture	0-5 5-10	5 [1.5] 4 [1.2]	4 [1.2] 3 [0.9]
Red fescue	0-5	3 [0.9]	2.5 [0.8]
Redtop	5-10	Not recommended	Not recommended

*Adapted from Chow (1959), Livingston et al. (1984), and Goldman et al. (1986).

S-5. Select a trial Manning's n. The minimum value for poor vegetation cover and low height (possibly, knocked from the vertical by high flow) is 0.033. A good initial choice under these conditions is 0.04.

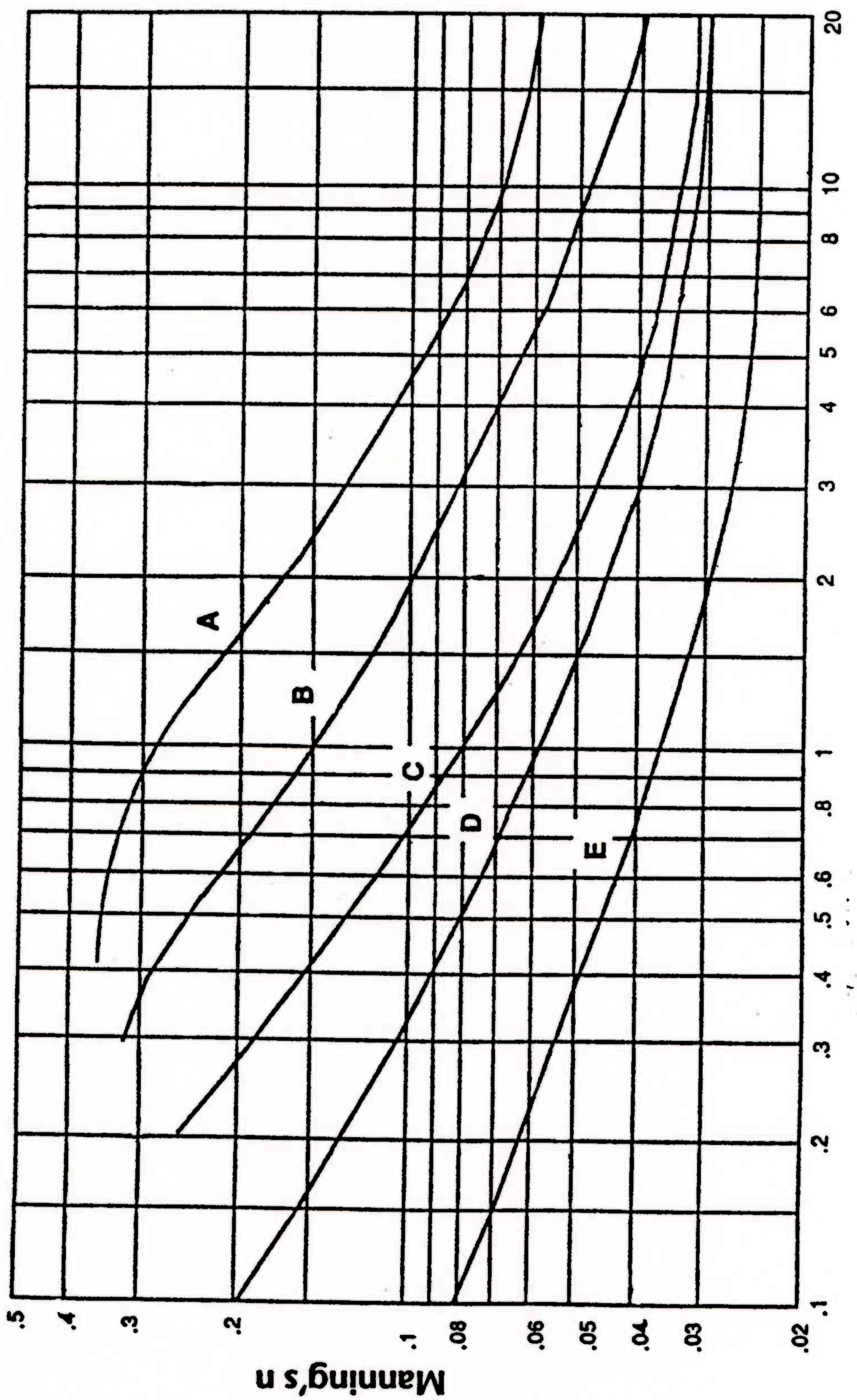
S-6. Refer to Figure G-2 (from Livingston et al., 1984, after U.S. Soil Conservation Service, 1954) to obtain a first approximation for VR.

S-7. Compute hydraulic radius, using the V_{max} from step S-4:

$$R = \frac{VR}{V_{max}} \qquad \text{Eq. G-14}$$

S-8. Use Manning's Equation to solve for the actual VR:

$$VR = \frac{1.49}{n} R^{1.67} s^{0.5} \qquad \text{Eq. G-15}$$



Note: VR is the product of velocity and hydraulic radius ($feet^2$/second).

Figure G-2. The Relationship of Manning's n with VR for Various Degrees of Flow Retardance (A-E)

S-9. Compare the actual VR from step S-8 and first approximation from step S-6. If they do not agree within 5 percent, repeat steps S-5 through S-9 until acceptable agreement is reached. If $n < 0.033$ is needed to get agreement, set $n = 0.033$, repeat step S-8, and then proceed to step S-10.

S-10. Compute the actual V for the final design conditions:

$$V = \frac{VR}{R} \qquad \text{Eq. G-16}$$

Check to be sure $V < V_{max}$ from step S-4.

S-11. Compute the required A for stability:

$$A = \frac{Q}{V} \qquad \text{Eq. G-17}$$

S-12. Compare the A computed in step S-11 of the stability analysis with the A from the biofiltration capacity analysis (step D-5).

If less area is required for stability than is provided for capacity, the capacity design is acceptable. If not, use A from step S-11 of the stability analysis and recalculate channel dimensions (refer to Figure G-1 or Eq. G-2).

S-13. Calculate the depth of flow at the stability check design flow rate condition for the final dimensions (refer to Figure G-1 or Eq. G-2 and use A from step S-11 of the stability analysis).

S-14. Compare the depth from step S-13 to the depth used in the biofiltration capacity design. Use the larger of the two and add 1 foot freeboard to obtain the total depth of the swale. Calculate the top width for the full depth using the appropriate equation. Skip this step in filter strip design.

S-15. Make a final check for capacity based on the stability check design storm and maximum vegetation height and cover (this check will ensure that capacity is adequate if the largest expected event coincides with the greatest retardance).

Use Equation G-1, the Manning's n selected in step D-2, and the calculated channel dimensions, including freeboard, to compute the flow capacity of the channel under these conditions.

If the flow capacity is less than the stability check design storm flow rate, increase the channel cross-sectional area as needed for this conveyance. Specify the new channel dimensions.

Completion Steps (C)

C-1. Review all of the Criteria and Guidelines for Biofilter Planning, Design, Installation, and Operation above and specify all of the appropriate features for the application.

EXAMPLE (BIOFILTRATION SWALE)

Preliminary Steps

P-1. Assume that Q for the 6-month, 24-hour storm was established by one of the recommended procedures to be 0.5 cfs.

P-2. Assume the slope is 2 percent

P-3. Assume the vegetation will be one of the recommended grass mixes.

Design for Swale Biofiltration Capacity

D-1. Set the winter grass height at 5 inches and design flow depth at 3 inches (0.25 ft).

D-2. Use n = 0.2.

D-3. Base the design on a trapezoidal shape.

D-4. Eq. G-9:

$$b \cong \frac{Qn}{1.49\, y^{1.67}\, s^{0.5}} - Zy$$

$Q = 0.5$ cfs $\qquad y = 0.25$ ft

$n = 0.2 \qquad s = 0.02$

$$b \cong 4 \text{ ft}$$

D-5. Figure G-1:

$T = b + 2yZ \qquad A = by + Zy^2$

$T = 5.5$ ft $\qquad A = 1.19$ ft^2

D-6. Eq. G-12:

$$V = \frac{Q}{A}$$

$V = 0.42$ feet per second < 0.9 feet per second (OK)

D-7. Eq. G-13:

$L = (V)\,(t)$ (60 seconds/minute)

For $t = 9$ min, $L = 227$ ft

Since b is less than the maximum value, it may be possible to reduce L by increasing b.

For example, if L = 180 ft is desired:

Eq. G-13: $V = \frac{L}{60t} = 0.33$ feet per second

Eq. G-12: $A = \frac{Q}{V} = 1.52\ ft^2$

Figure G-1: $b = \frac{A - Zy^2}{y} = 5.33$ ft

Check for Channel Stability

S-1. Base the check on passing the 100-year, 24-hour storm runoff flow through the swale. Assume that Q for that storm was established by one of the recommended procedures to be 1.6 cfs.

S-2. Base the check on a grass height of 3 inches with "fair" coverage (lowest mowed height and least cover, assuming flow bypasses or does not occur during grass establishment).

S-3. Table 6-1: Degree of retardance = D.

S-4. Assume soils analysis has established soils as erosion resistant.

Table G-3: $V_{max} = 5$ feet per second

S-5. Select trial $n = 0.04$

S-6. Figure G-2: $VR = 3\ ft^2/s$

S-7. Eq. G-14: $R = \frac{VR}{V_{max}}$

$R = 0.6$ ft

S-8. Eq. G-15: $VR = \frac{1.49}{n} R^{1.67} s^{0.5}$

$VR = 2.24\ ft^2/s$

S-9. VR from step S-8 < VR from step 6 by > 5 percent.

Select new trial $n = 0.038$

Figure G-2: $VR = 4\ ft^2/s$

Eq. G-14: $R = 0.8$ ft

Eq. G-15: $VR = 3.81\ ft^2/s$ (within 5 percent of VR = 4)

S-10. Eq. G-16: $V = \frac{VR}{R} = \frac{3.81}{0.8}$

$V = 4.76$ feet per second < 5 feet per second (OK)

S-11. Eq. G-17: $A = \frac{Q}{V} = \frac{1.6}{4.76} = 0.34$

S-12. Stability $A = 0.34\ ft^2$ from step S-11 < capacity $A = 1.19$ or $1.52\ ft^2$ from step D-5 or D-7 (OK).

If stability A > capacity A, it will be necessary to select new trial sizes for width and flow depth (based on space and other considerations), recalculate A, and repeat steps S-11 and S-12.

S-13. Figure G-1: $y = \frac{-b \pm (b^2 + 4ZA)^{0.5}}{2Z}$ (quadratic equation solution)

For $b = 5.33$ ft, $y = 0.06$ ft (positive root)

S-14. Greater depth is 0.25 ft, which was the basis for the biofiltration capacity design (step 1). Add 1 ft freeboard to that depth.

Total channel depth = 1.25 ft

Top width $= b + 2yZ = 5.33 + (2)(1.25)(3) = 12.83$ ft

S-15. $Q = \frac{1.49}{n} AR^{0.67} s^{0.5}$

$A = by + Zy^2$

For $b = 5.33$ ft and $y = 1.25$ ft, $A = 11.35\ ft^2$

$R = \frac{by + Zy^2}{b + 2y\,(Z^2 + 1)^{0.5}}$

For $b = 5.33$ ft and $y = 1.25$ ft, $R = 0.86$ ft

$s = 0.02 \quad n = 0.2$

$Q = 10.8$ cfs > 1.6 cfs (OK)